ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

SIMULATION OF EBR-II SHRT-17 TEST BY RELAP5-3D© CODE

SAPIENZA UNIVERSITÀ DI ROMA

A. Del Nevo[1], E. Martelli[2]

(1) ENEA CR Brasimone, (2) ENEA/UNIROMA

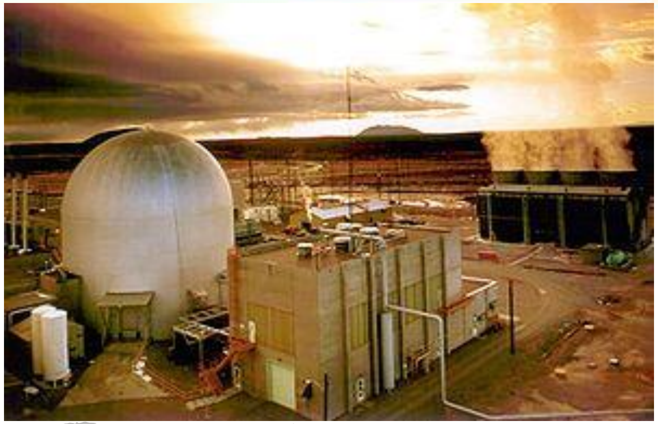
International RELAP5 Users Group Meeting

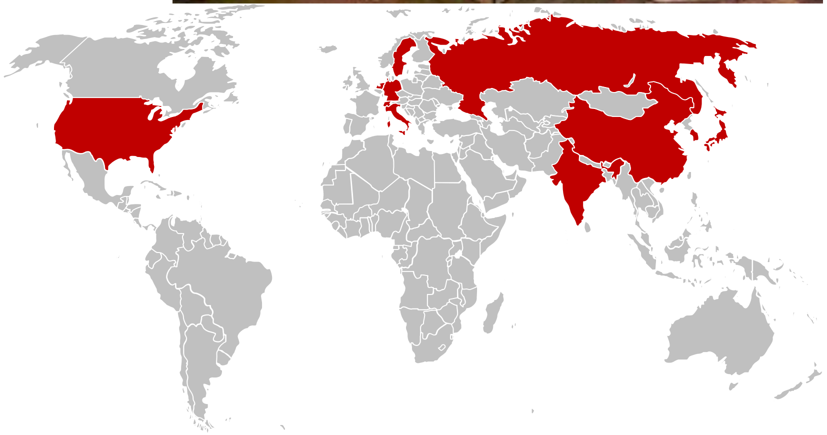
September 11 – 12, 2014

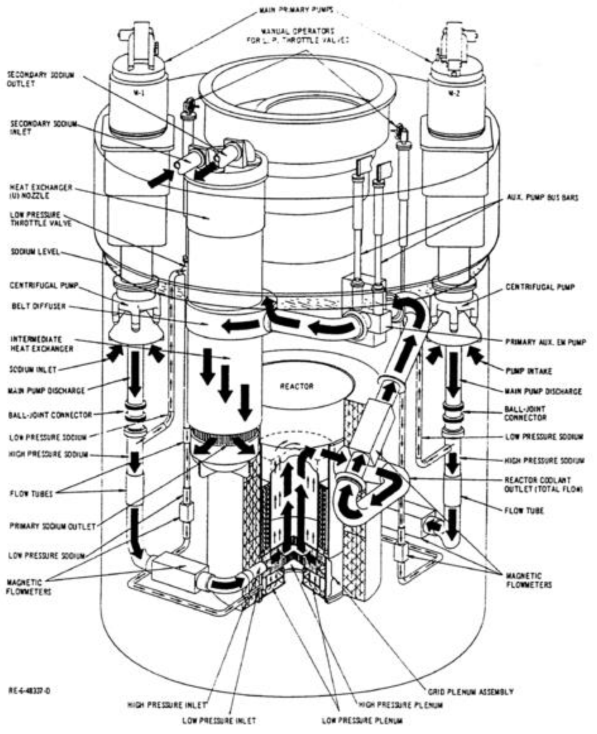
Residence Inn, 635 W. Broadway Idaho Falls, ID 83402

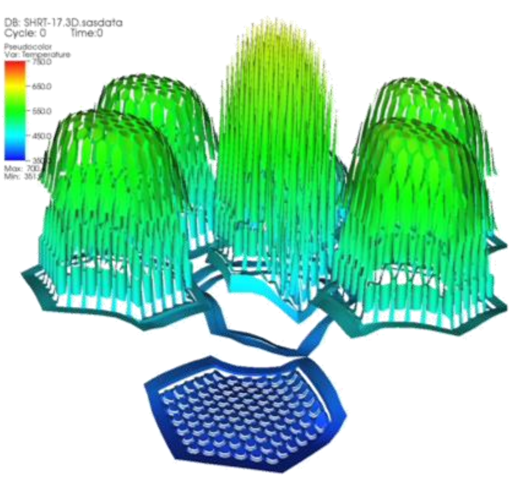
IAEA CRP Benchmark on EBR-II

- Stefano Monti, IAEA
- ANL, US providing data and technical coordination
- EBR-II SHRT-17 and SHRT-45R provided by ANL
  - Protected and Unprotected Loss of Flow
  - Multi-physics activity based on experimental data









Participants	
China	France
Germany	Italy
India	Japan
Korea, republic of	Netherlands
Russian Federation	Sweden
Switzerland	**USA**

LIST OF CONTENTS

- OBJECTIVES OF THE ACTIVITY
- INTRODUCTORY REMARKS
- NODALIZATION DESCRIPTION AND ASSUMPTIONS
- VERIFICATIONS FOR BLIND CALCULATIONS
- SHRT-17 TEST: PROTECTED LOSS OF FLOW
- BLIND CALCULATION RESULTS AND COMPARISONS WITH EXP DATA
- SUMMARY

Objectives of the Activity

The planned **objectives** are :

1. to compare best-estimate TH-SYS code calculations to experimental data, thus to **validate RELAP5-3D© system code in simulating sodium fast reactor designs**

2. to identify and, as far as possible, to **quantify the code limitations and the source of uncertainties** in simulating postulated accidents occurring in liquid metal FR designs

3. to improve the understanding of the TH processes and phenomena observed in EBR-II test

4. **to improve the understanding of FR neutronics, TH and SYS analysis**

5. to compare the performances of TH system codes in the domain of interest

6. **to develop reliable approaches for the application of TH-SYS codes in safety analysis** of new generation FR systems (i.e. LFR), **including the coupling** with CFD *and NK*

INTRODUCTORY REMARKS: WORK PLAN

Work plan:

- ❑ **Year 1**: Preparation of input deck. Steady state calculation.
  1st RCM meeting

- ❑ **Year 2**: Blind test simulation analysis. Preliminary assessment of the results (experimental vs. blind simulations and among simulations).
  2nd RCM meeting

- ➢ **Year 3**: Post test analysis and sensitivity. Code assessment: uncertainties analyses, identifications of model/code/data weakness, R&D needs, etc.
  3rd RCM meeting

- ❑ **Year 4/5**: Assessment of code capabilities, reporting, writing paper(s), and contributing to the IAEA technical publications. 4th RCM meeting

Current status:

- ❖ TH nodalization of EBR-II (configuration SHRT-17) completed. Steady state achieved. Blind calculation of SHRT-17 test carried out and submitted. Post test analysis finalized analysis in progress

- ❖ CFX models of XX09 fuel assembly prepared

- ❖ Neutronics activities: ERANOS model in progress.

INTRODUCTORY REMARKS

Framework:

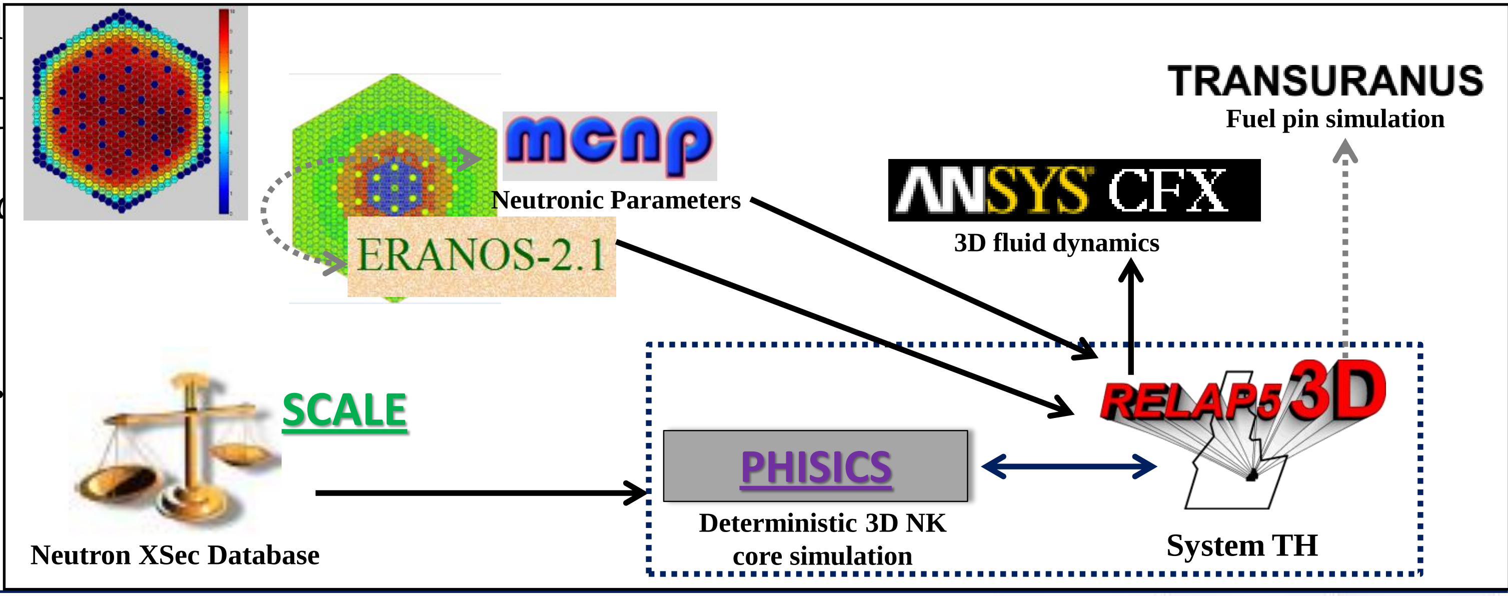
- MS thesis in Energy Engineering of Emanuela Martelli
- MISE funded AdP-2012 Project
- IAEA CRP on EBR-II

Blind calculation SHRT- 17 performed with:

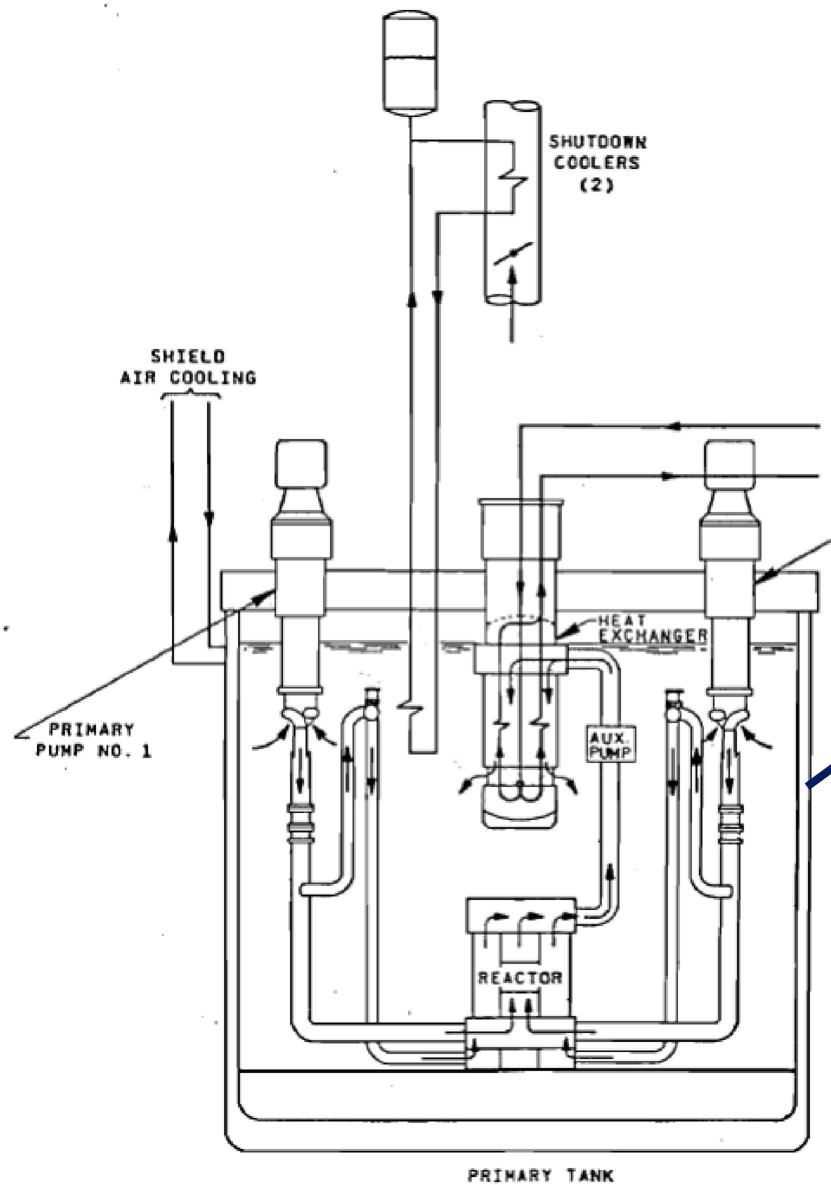
- Workstation HP: Operative system WINDOWS 7 Professional (64bit); Intel® XEON @ 3.2GHz; RAM 16 GB
- Reference TH-SYS code: **RELAP5-3D©v4.0.3** (INL-US)

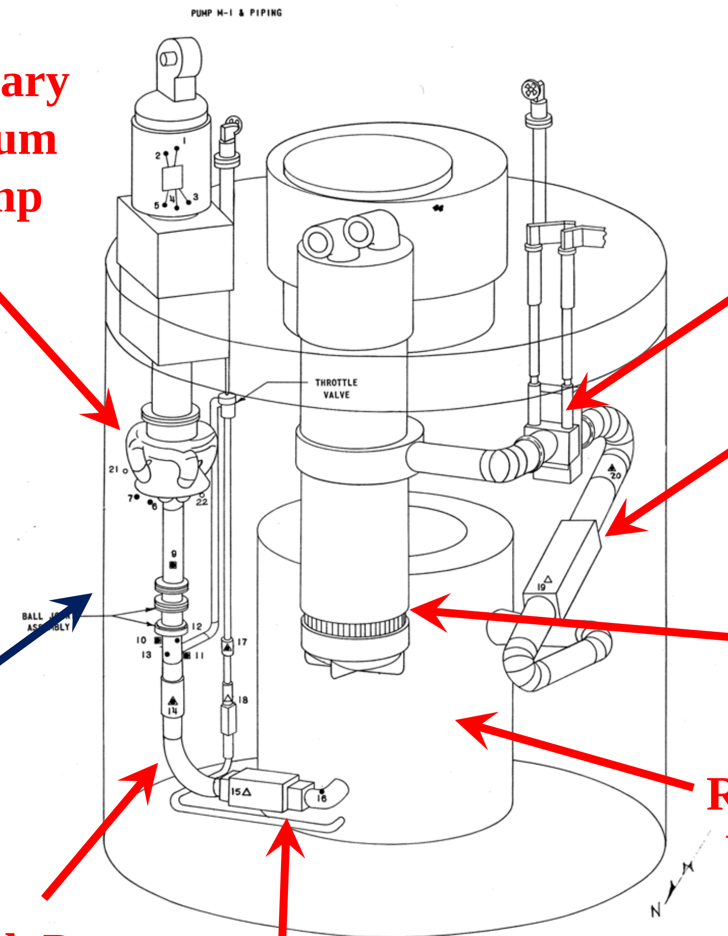
CFD and deterministic and

- Reference CFX code: C
- *Planned neutronics co*
  - PHISICS, SCALE
  - ERANOS 2.1 → **P.**



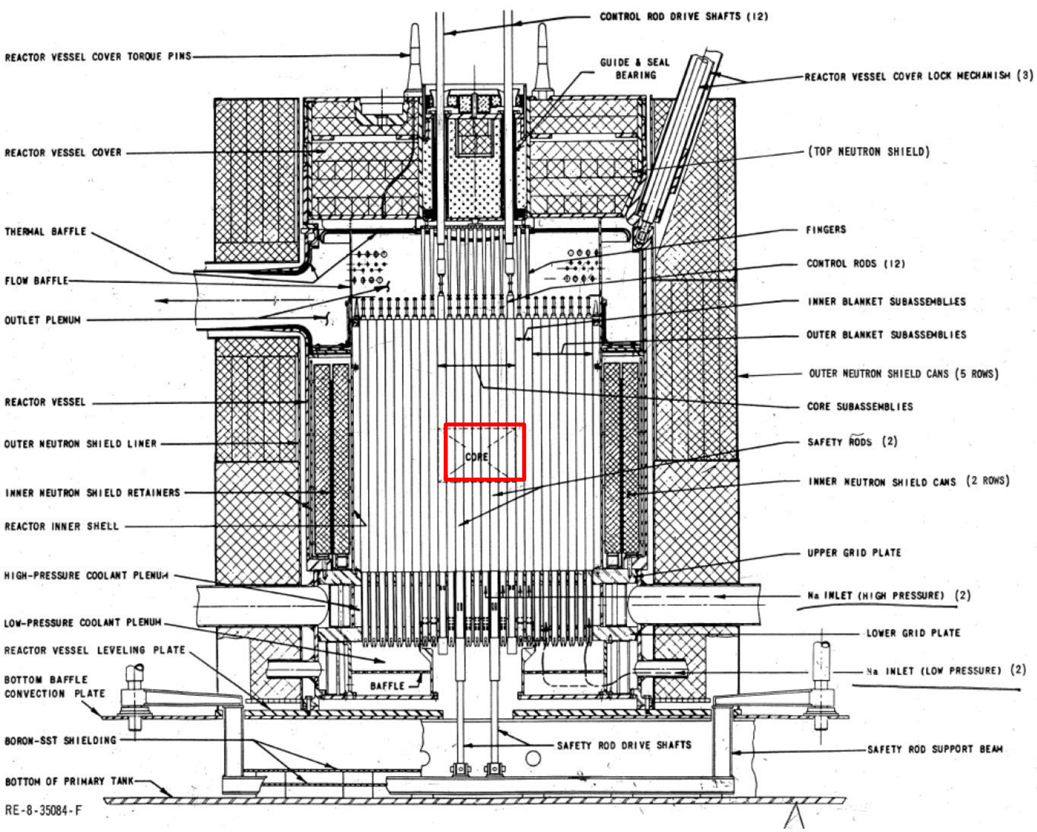
EBR-II OVERVIEW

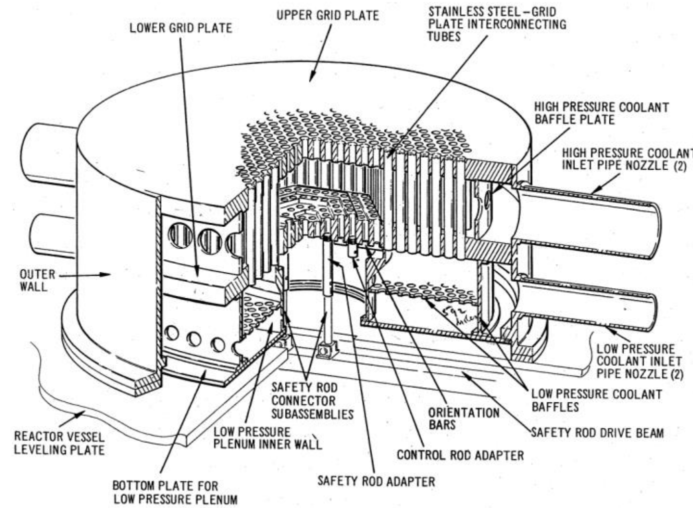


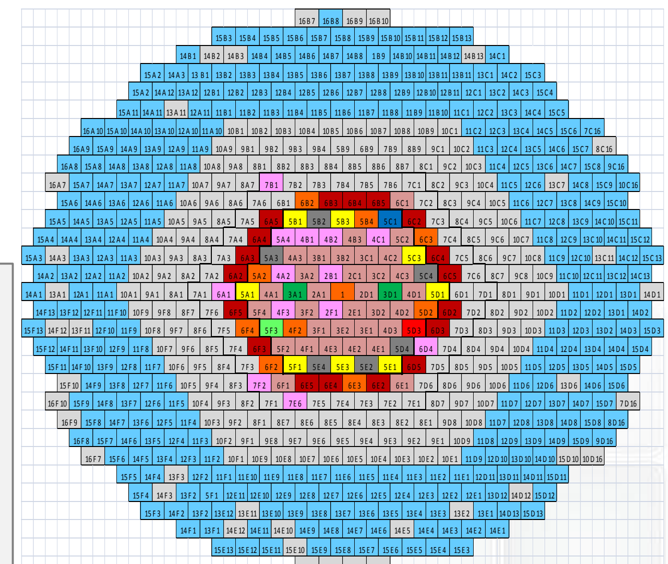


- All primary system components were submerged in the primary tank
- Argon cover gas
- Two pumps drew sodium from the pool to the two inlet plena

EBR-II OVERVIEW



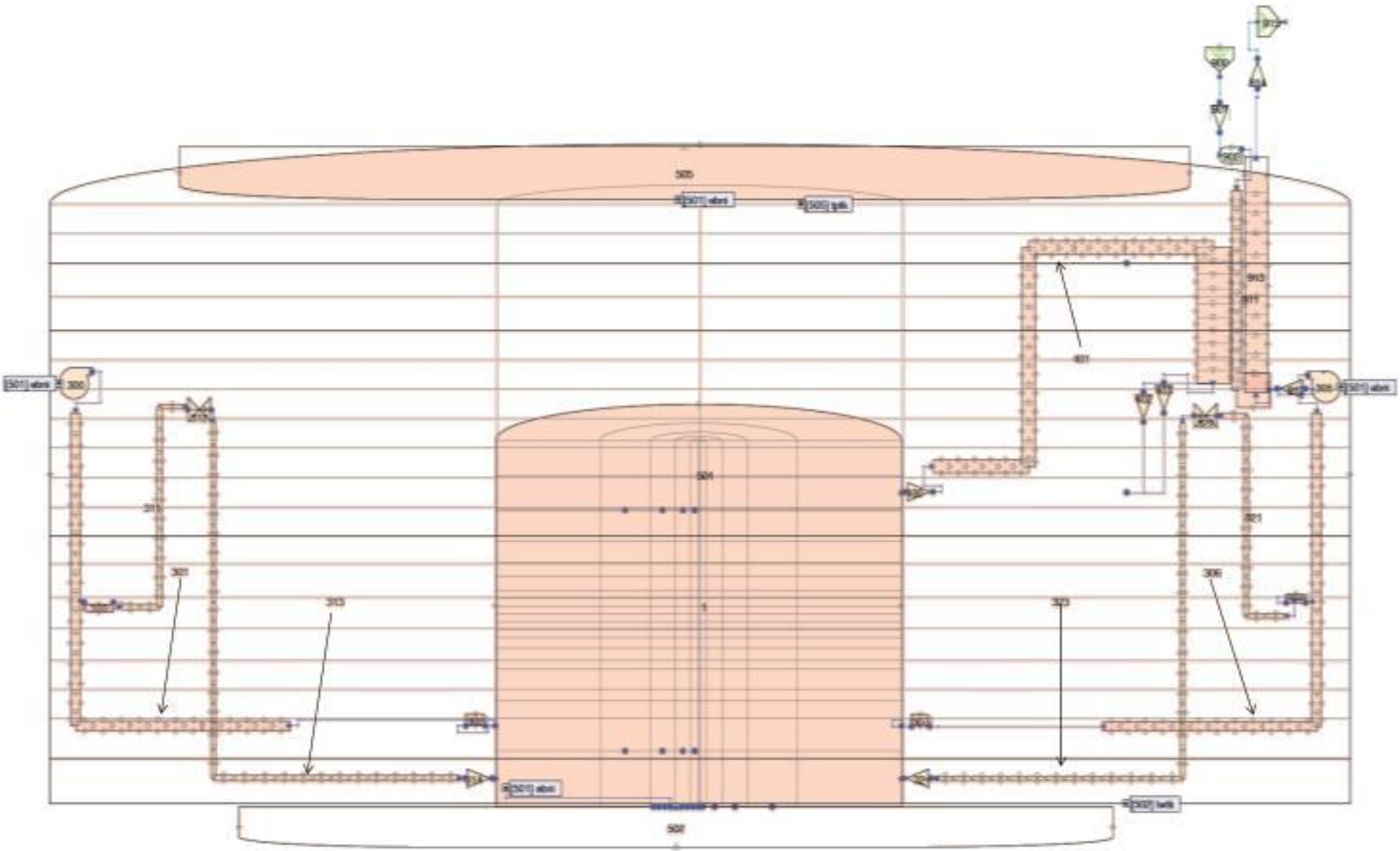




LEGEND	xSy	
x	row in sector	1,...16
S	sector	A, B, C, D, E, F
y	position in row	1,...13

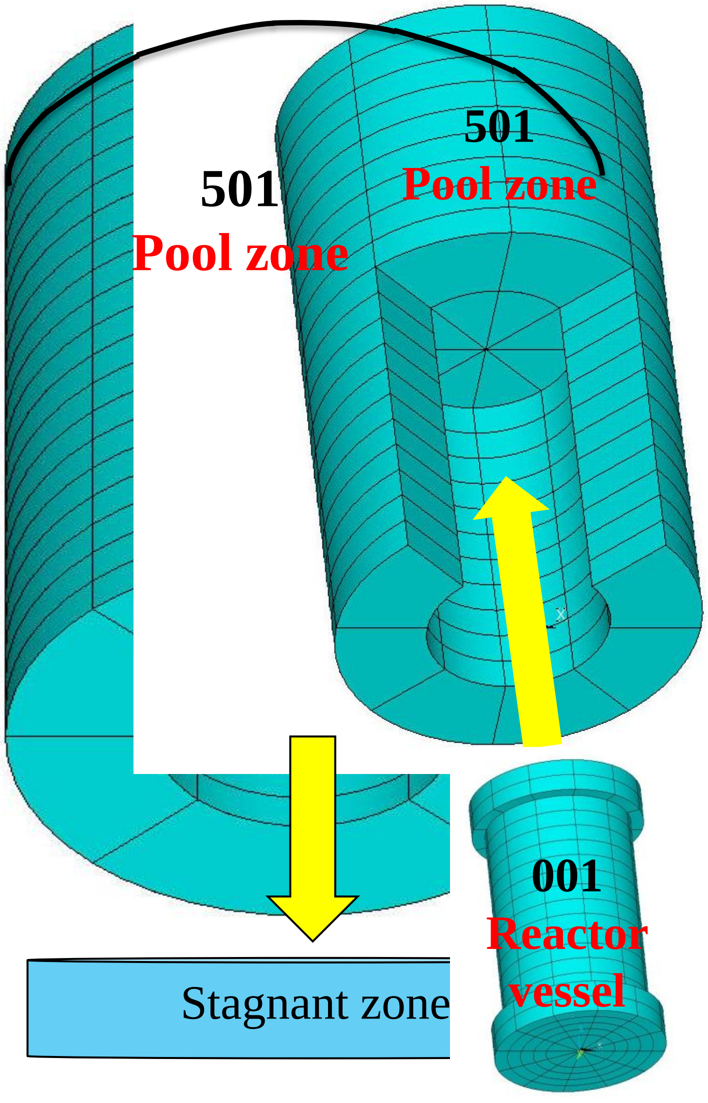
Reactor features

- 637 assemblies
- Core divided in three regions: central core, expanded core and outer blanket
- Inner core and the expanded core regions received sodium from the high-pressure inlet plenum.
- Outer blanket region received sodium from the low-pressure inlet plenum
- Sodium discharged into the common upper plenum
- Neutron shielding surrounded the reactor, upper plenum and lower plena with the exception of the inlet and outlet piping



3D modelling of primary tank

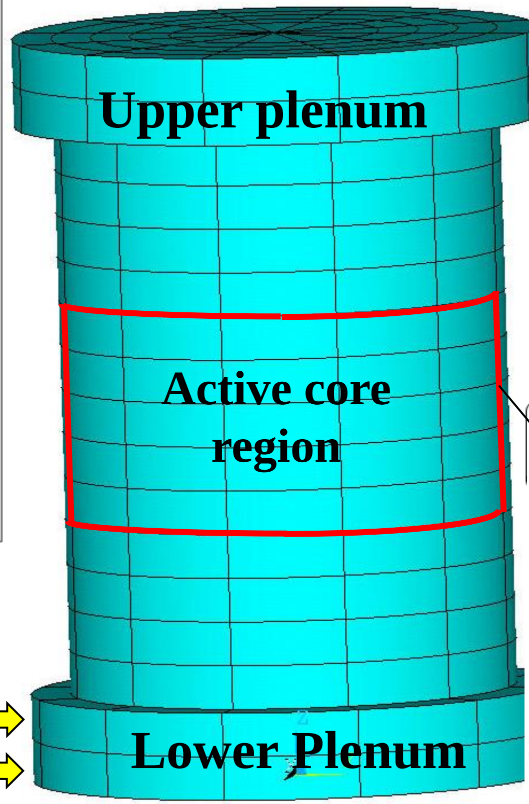
- Pool region → 3D component
- Reactor region → 3D component
  - Core bypass modeled with MULTID component of reactor region
- Connection with MCP, IHX modeled according with the real 3D configuration
- Axial meshes of pool region have vertical lengths equal or multiple with respect to reactor region, pipes and IHX
- Careful model of heat structures where possible:
  - Rough estimation of metal in 1) dead zone, 2) IHX internal passive structures, 3) MCP internal passive structures



ENEA AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

3D modelling of the Reactor Vessel

- Driver FA modeled one by one with pipe components according with the geometrical description reported in the specifications
- Blanket region modeled with equivalent PIPE components according with the azimuthal configuration, grouping reflector and blanket FAs, separately



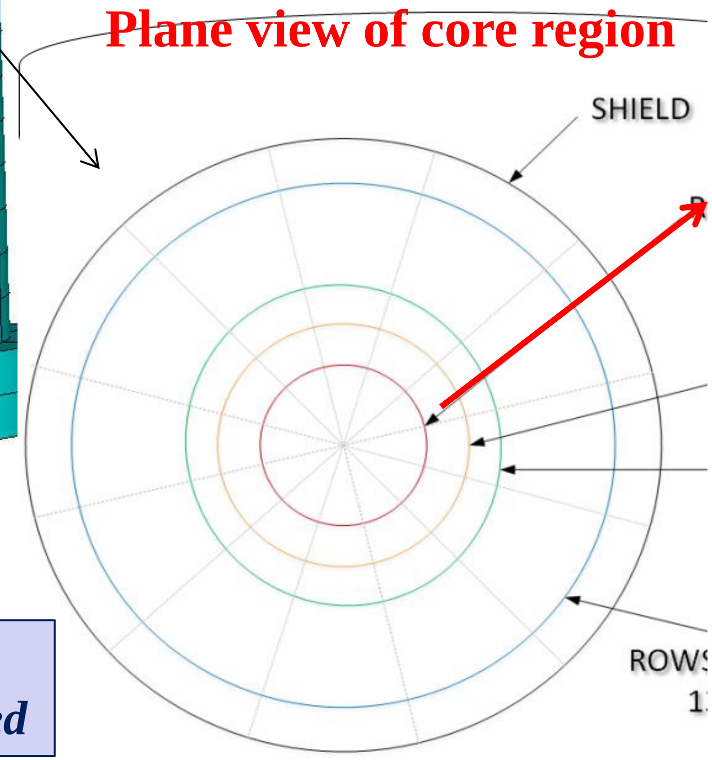
To Z-Pipe

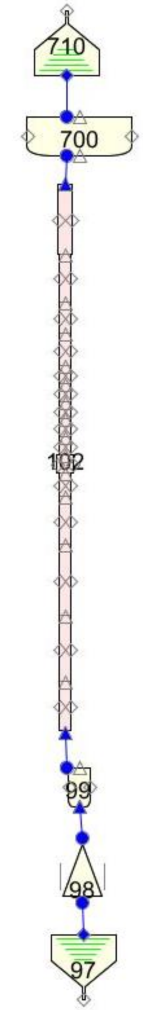
High P inlet pipe

Low P inlet pipe

Axial view of the core region

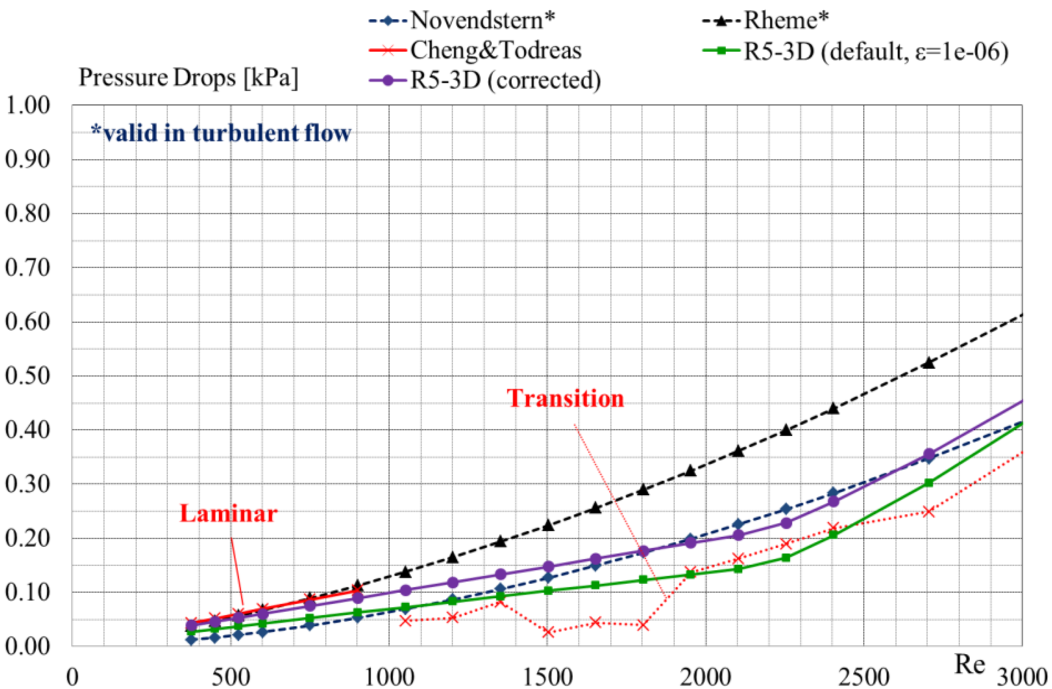
Plane view of core region

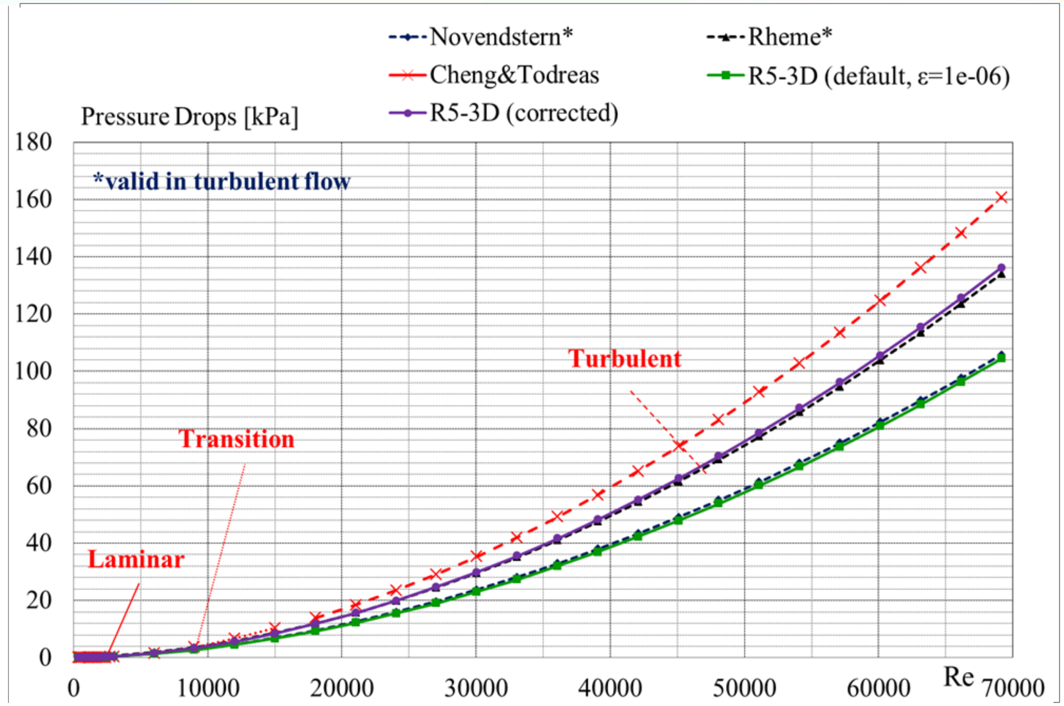




- **SHRT-17 core model configuration completed**
- ***SHRT-45R core model configuration to be implemented***

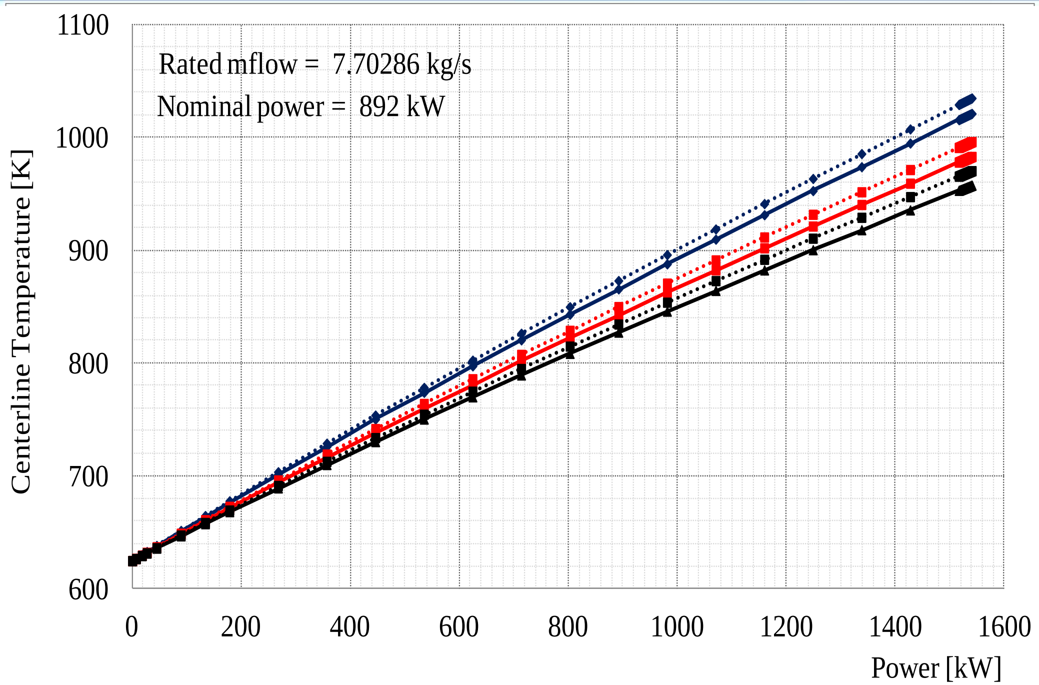
TESTING FA PERFORMANCES: PRESSURE DROPS

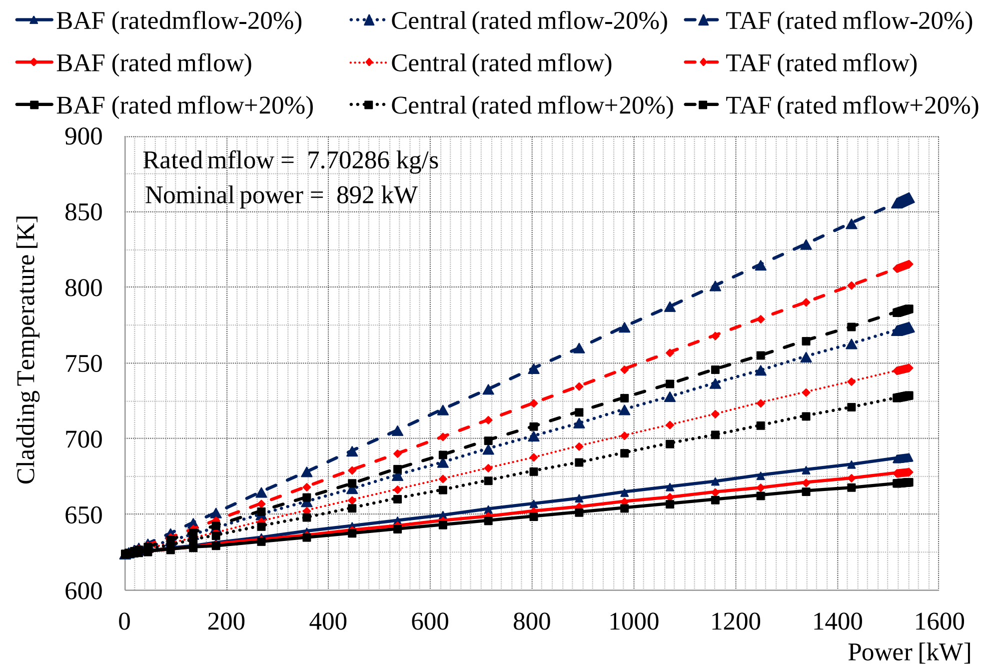




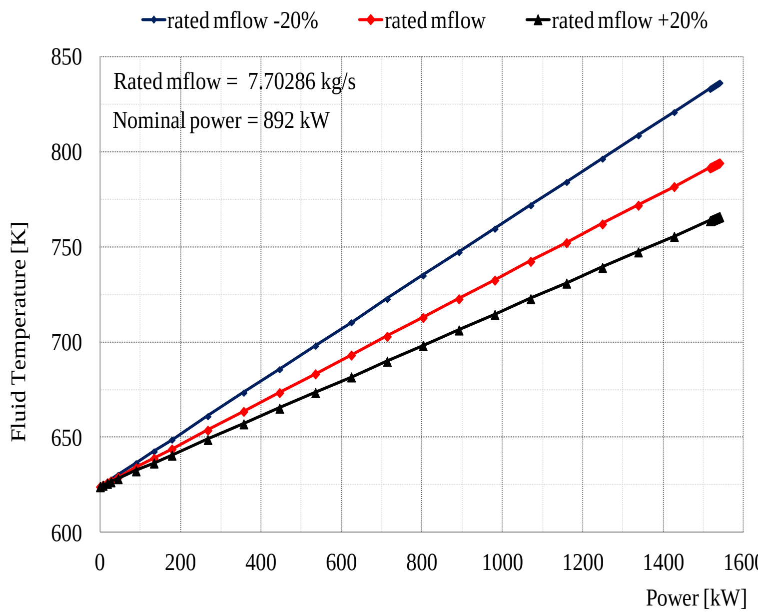
- MARK II-AI dynamic pressure drop in wire wrapped fuel bundle
  - "100% Mflow" in Figure corresponds with minimum nominal mass flow rate → Driver Mark II–AI [6,C1]
  - Evaluation of the effect of surface roughness accounted in the turbulent friction factor correlation @ nominal steady state conditions
  - Quantification of pressure drop in the wire wrapped zone in the range of mass flow of interest @ nominal steady state conditions
  - **CFD calculations may support the evaluation of DP in FA**

TESTING FA PERFORMANCES: HEAT EXCHANGE





- Evaluation of heat transfer in MARK-II AI FA considering the parameters of benchmark specifications (i.e. coolant, cladding, and fuel centerline Ts)
  - Nominal parameters refer to assembly with MAX power Driver MARK II-AI [2,A1]
  - Fuel centerline temperature cannot be evaluated w/o considering modifications in hot conditions and occurring during irradiation
    → "Arbitrary" gap size was set to 0 to avoid fuel centerline temperature exceeding too much from melting T



SHRT-17 Test Blind Calculation: Steady State Results

- DP distributions in overall system and MCP homologous curves are checked
- Power and mass flow distribution according with RUN129c
- Steady state achieved with reasonably accuracy, *but…*
  - Mass flow rate distribution in the FA is satisfactory. Underestimation of RING 2 connected with overall DP constraints → Improvements in DP distribution in low P flow and blanket FA orifices are needed
  - Thimbles' mass flow rates are have been provided in the specification as constant value for all EXP FA

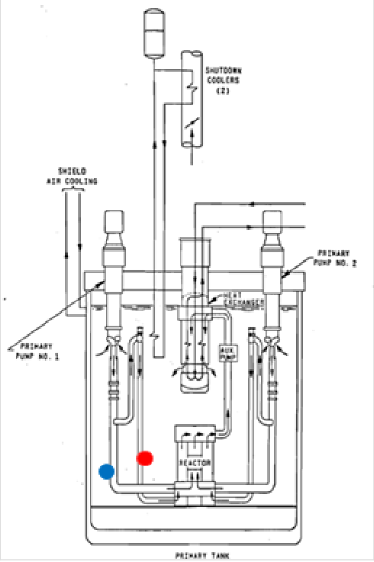
RING	TYPE	# FA	MASS FLOW	R5-3D	ERR
	Reflector	12	[redacted]	**1.95**	[redacted]
	Blanket	12	[redacted]	**3.56**	[redacted]
Row 7	Reflector	33	[redacted]	**0.17**	[redacted]
	Experimental	3	[redacted]	**0.68**	[redacted]
Row 6	Experimental	2	[redacted]	**3.87**	[redacted]
	High Flow Driver	18	[redacted]	**3.86**	[redacted]
	Reflector	2	[redacted]	**0.17**	[redacted]
	Partial Driver	5	[redacted]	**2.62**	[redacted]
	Driver	3	[redacted]	**3.56**	[redacted]
Row 5	Control Rod	8	[redacted]	**3.62**	[redacted]
	Partial Driver	3	[redacted]	**3.06**	[redacted]
	SS FA	6	[redacted]	**0.69**	[redacted]
	Experimental	1	[redacted]	**4.36**	[redacted]
	XX10	1	[redacted]	**0.59**	[redacted]
	Driver	3	[redacted]	**4.37**	[redacted]
	XX09	1	[redacted]	**3.02**	[redacted]
	Dummy	1	[redacted]	**0.91**	[redacted]
Row 4	Driver	12	[redacted]	**5.03**	[redacted]
	Experimental	5	[redacted]	**5.04**	[redacted]
	Partial Driver	1	[redacted]	**3.28**	[redacted]
Row 3	Safety	2	[redacted]	**5.14**	[redacted]
	Driver	10	[redacted]	**6.55**	[redacted]
Row 2	Driver	4	[redacted]	**7.30**	[redacted]
	Experimental	2	[redacted]	**7.37**	[redacted]
Row 1	Partial Driver	1	[redacted]	**3.78**	[redacted]

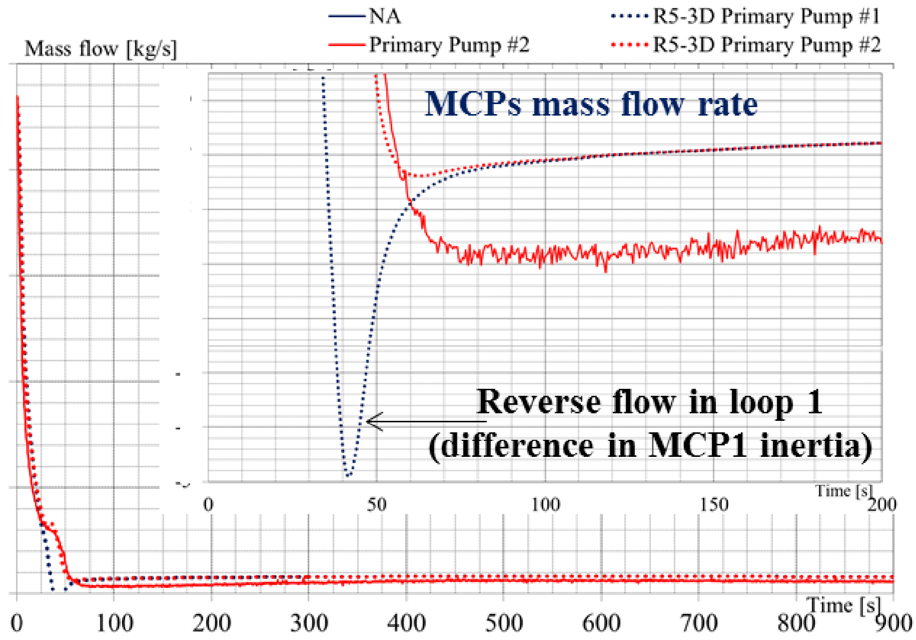
7-6	IHX PS outlet	kg/s	[redacted]	454.1	[redacted]
7-7	IHX SS mass flow rate	kg/s	[redacted]	311.43	[redacted]

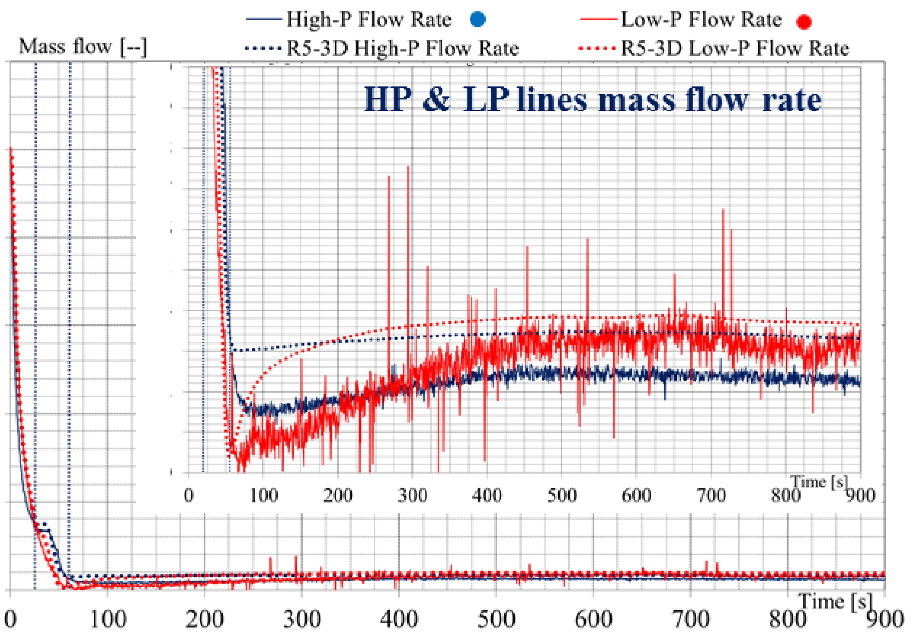
SHRT-17 Blind results: Mass flow rates

SHRT-17 Test

- Sequence of events as in SBO
  - loss of IHX flow rate → t=0
  - MCP trip and coastdown → t=0
  - SCRAM → t=0
  - End of the transient → t=900s

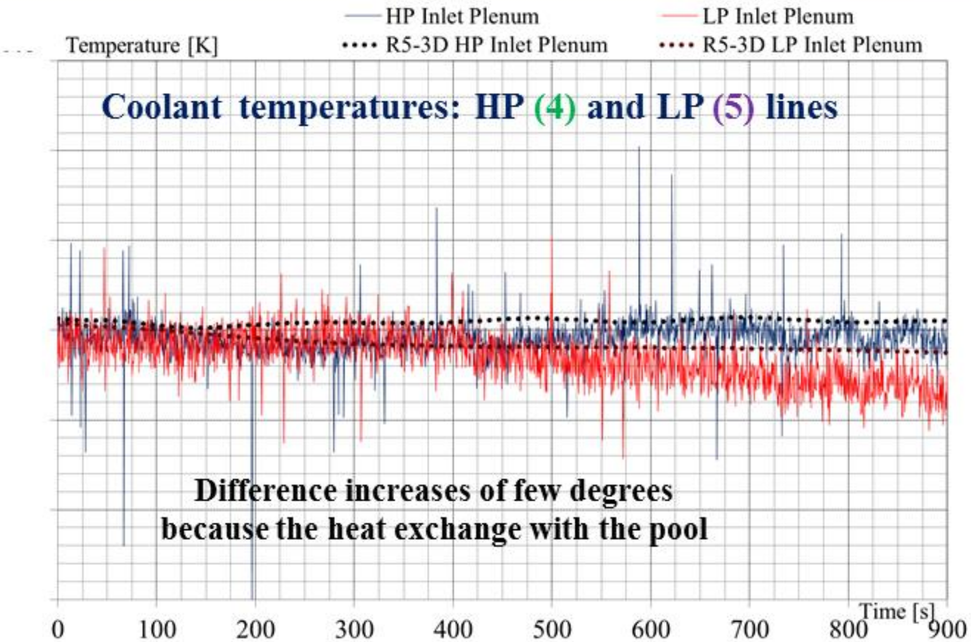


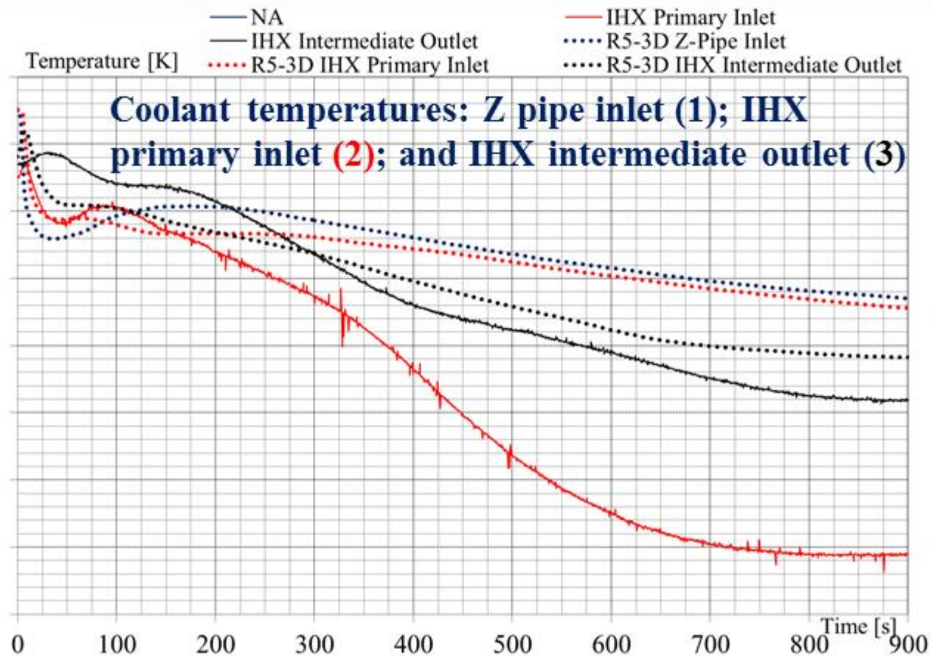


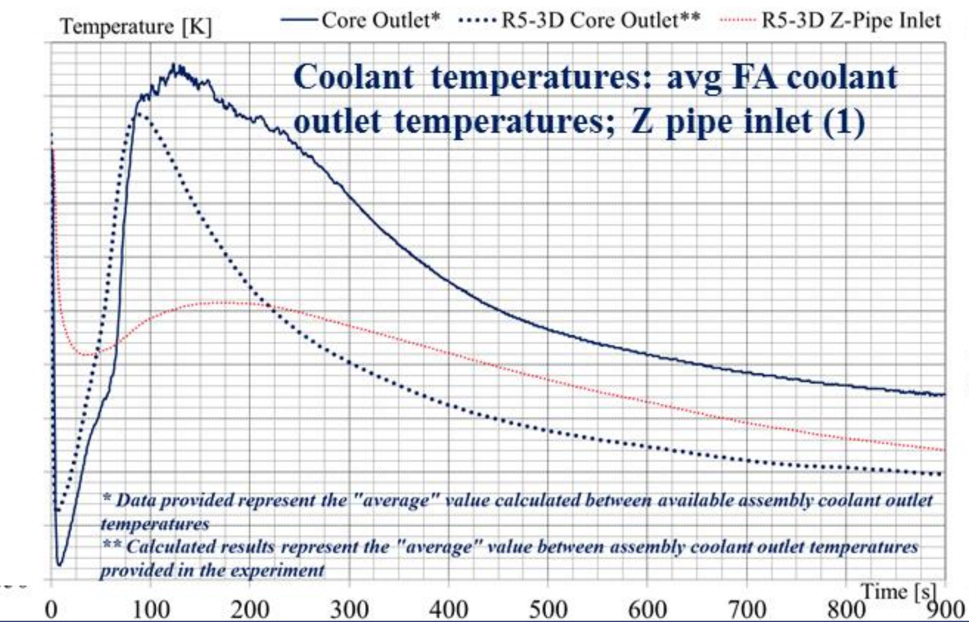


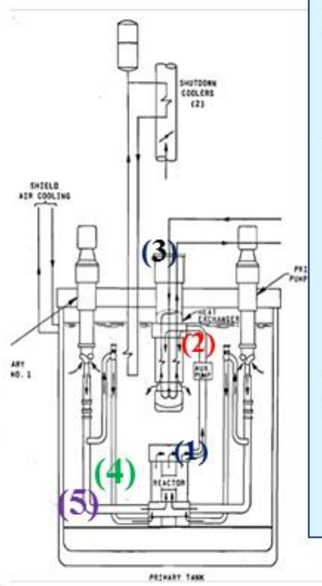
- Qualitative agreement between EXP data and CALC
- Minor overestimation of mass flow rate during coastdown → unpredictable Δt of -2.5s
- Overestimation of mass flow rate: when MCPs are at rest increase of NC
- Reverse flow in MCP1 pump loop is not confirmed by the EXP data. However, it was predicted by some benchmark participant simulations
- Underestimation of ΔP is addressed in post test…

SHRT-17 Blind results: PS coolant T



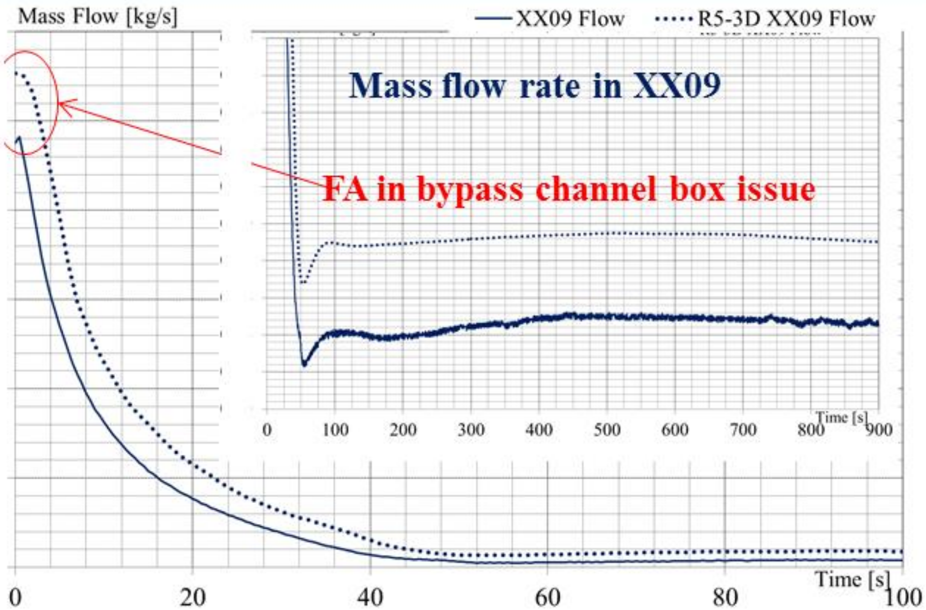


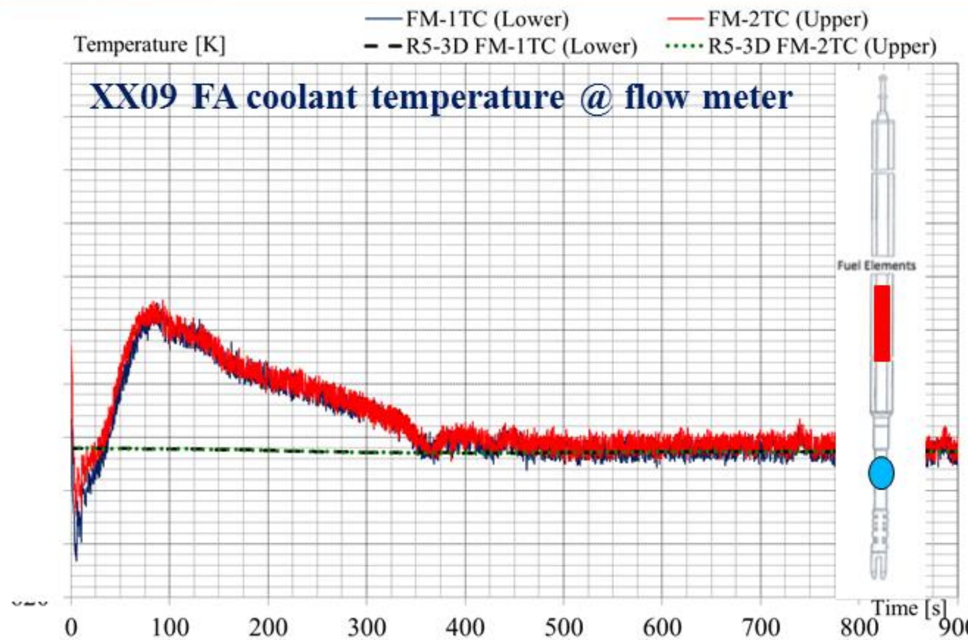


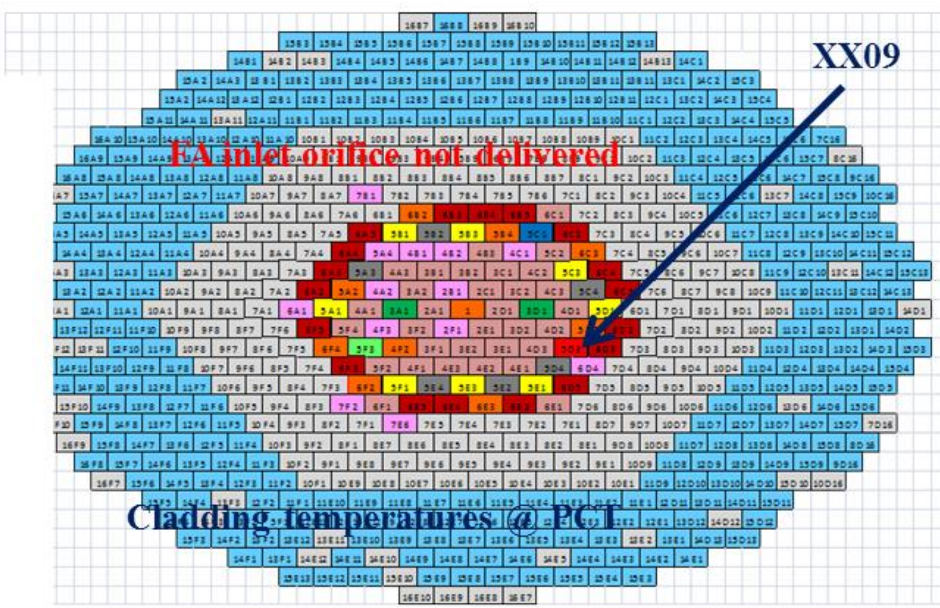


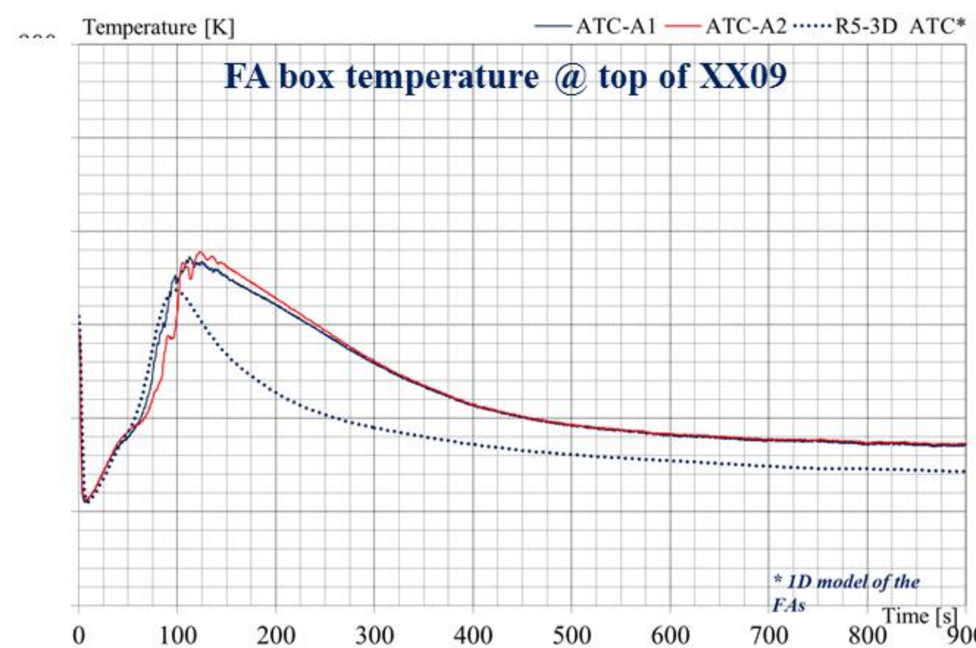
- Qualitative agreement between EXP data and CALC
- EXP IHX coolant temperature @ 500s drops below the pool temperature → unpredictable effect due to the top IHX structures.
- Differences in IHX intermediate outlet temperatures can be connected with minor local effect

SHRT-17 Blind results: XX09 sample parameters

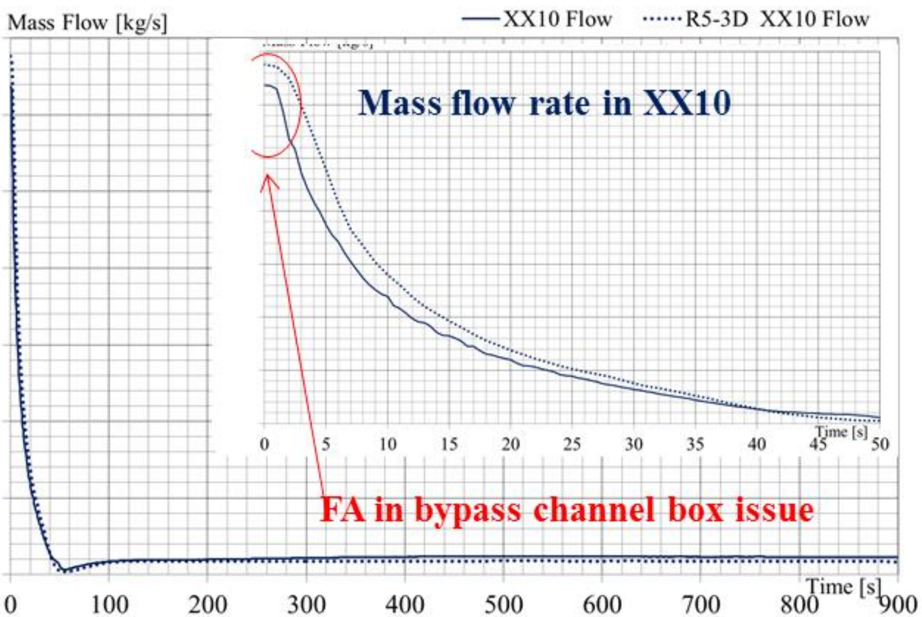


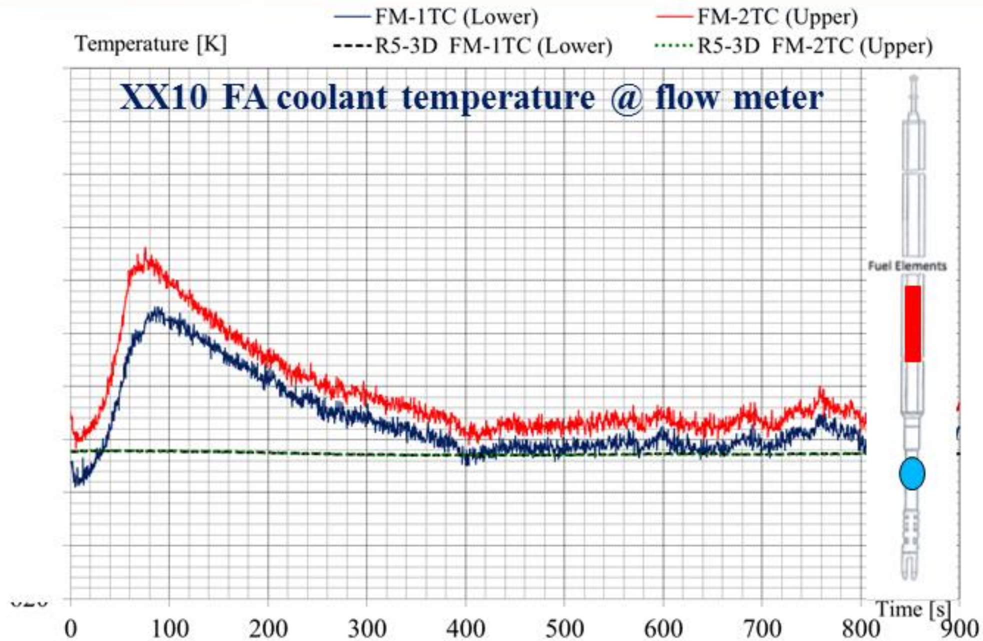


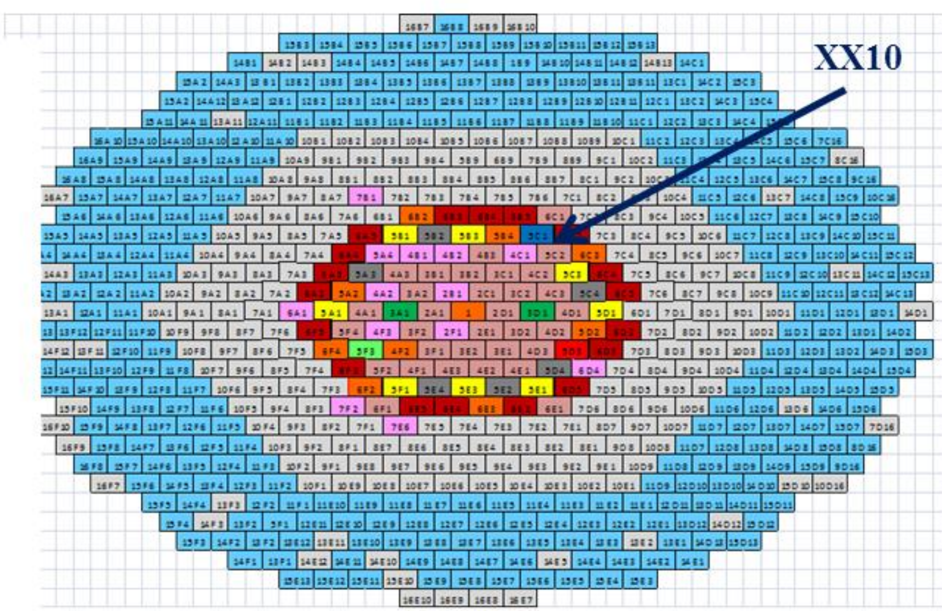


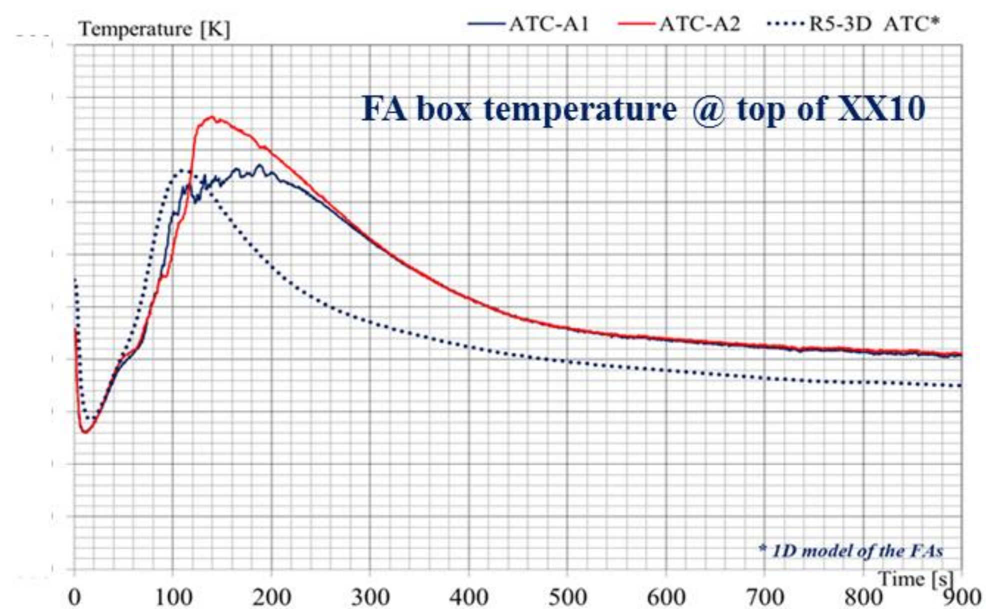


SHRT-17 Blind results: XX10 sample parameters



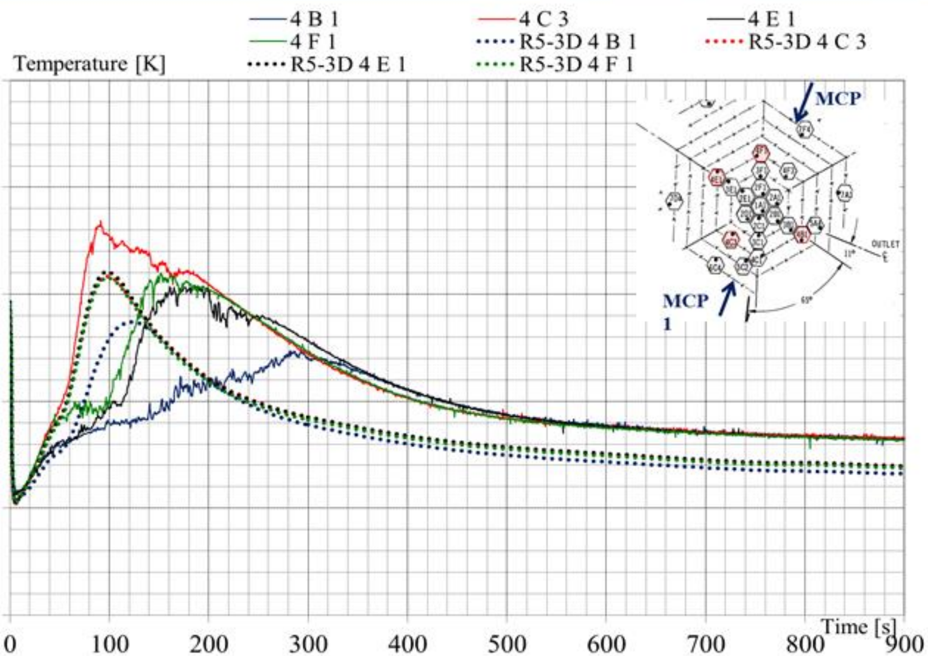


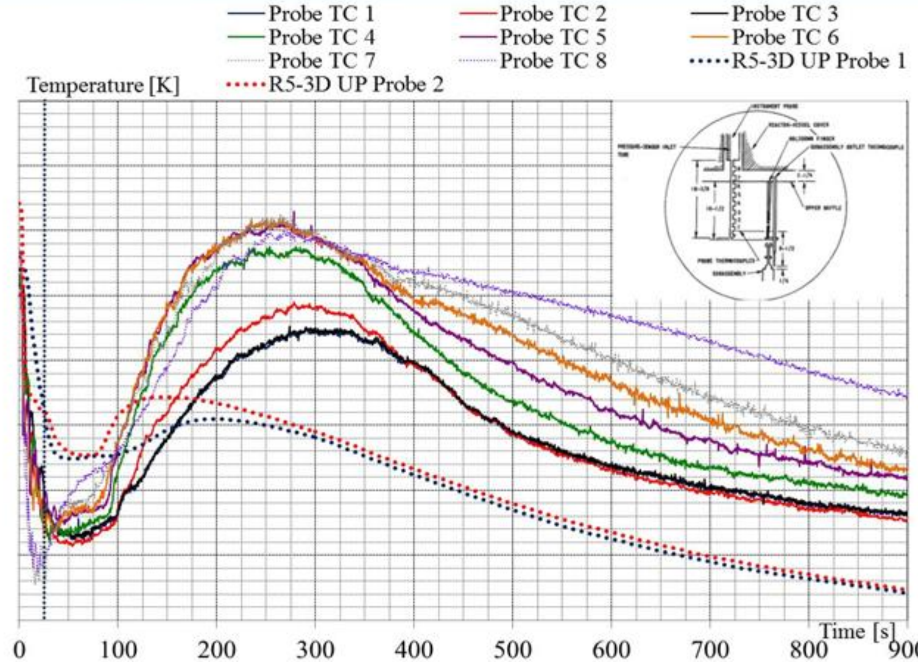




SHRT-17 Blind results: Sample coolant temperatures

ENEA AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

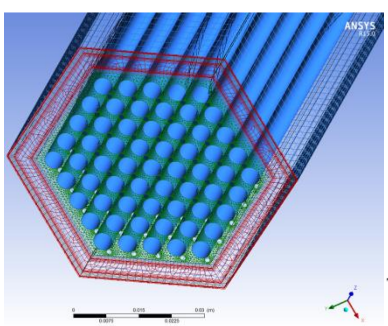


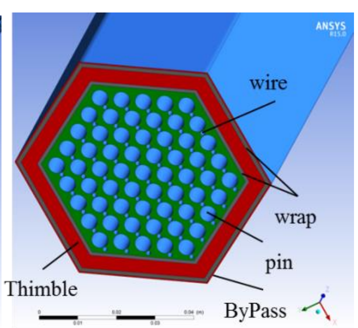


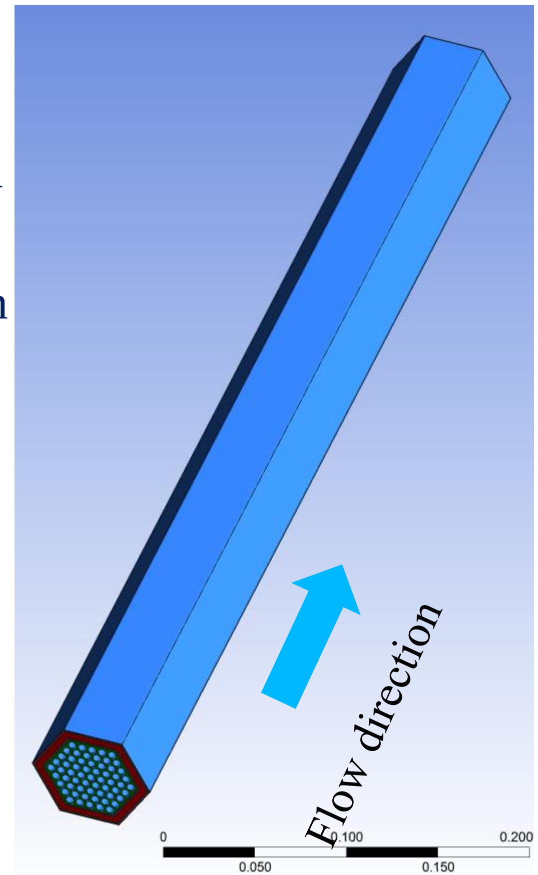
- Qualitative agreement between EXP data and CALC. All parameter trends are coherent with the experimental data thus the blind simulation is satisfactory.
- Underestimation of mass flow rate has major impact in affecting the temperature trends, but…
  - temperatures at flow meter highlights higher energy stored in the reactor zone (i.e. metallic structures, core bypass, channel in the channel boxes, etc.)
- INFO on FA orifices have not been delivered
- Trends of some parameters are "challenging" for the code and the simulation, e.g. temperature stratification in UP, axial conduction, quantification of cold zones in IHX, detailed irradiation effects, behavior of the impeller of the MCPs, etc…
- Some improvements are achieved in the post test calculation, but further are possible following the additional data release

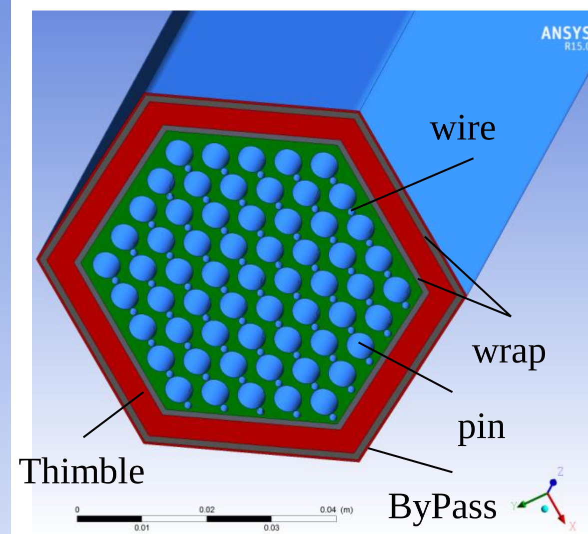
CFD activity: XX09 FA Model

- Main focus on *detailed temperature distribution* in the generic FA
- Reference geometries: **XX09-XX10** FA.
- The model includes all the wire-wrapped region and all the subchannels in the FA without any symmetry plane, the convection in the **fluid**, the conduction in the internal and external **wrap**, the **thimble** region and the **bypass**.
- **Input**: mass flow rates (RELAP5), inlet temperatures (RELAP5), gamma deposition (minor), flux distribution (minor)
- **Output**: detailed temperature distribution in the fluid and in the thimble region
- The model is in principle time-dependent.
- The reference number of nodes is $\mathbf{33 \cdot 10^6}$









The wall heat flux q″ is imposed.

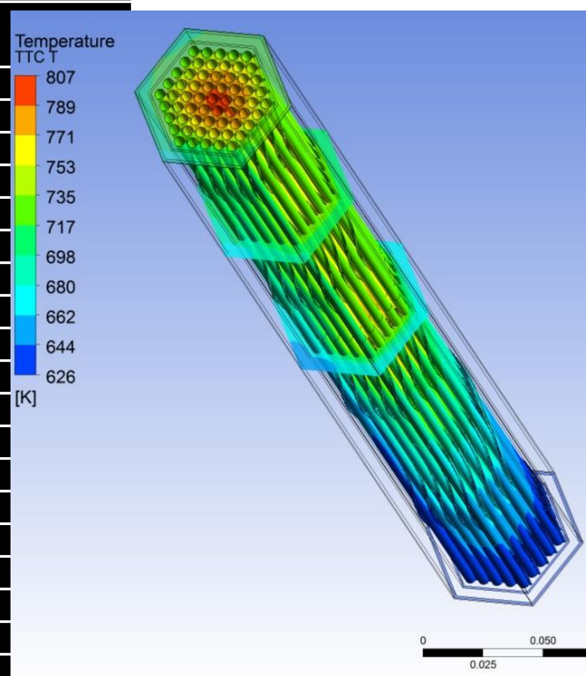
First test case (XX09) stationary: m_{FA}=2.37 kg/s, $m_{THIMBLE}$=0.25 kg/s, W_{tot}=464.7 kW ⇨ **q″≈1.87 MW/m²**

CFD ACTIVITY: XX09 FA TEMPERATURES IN STEADY STATE CONDITIONS

First test case (XX09) stationary: m_{FA}=2.37 kg/s, $m_{THIMBLE}$=0.25kg/s, W_{tot}=464.7 kW, T_{inlet} =626.1 K

A preliminary comparison with experimental results is *ongoing*

	ANL exp	CFD CSO3	err[K]
Lower Flowmeter Temperature (FM-1TC)	[redacted]	626.1	[redacted]
Upper Flowmeter Temperature (FM-2TC)	[redacted]	626.1	[redacted]
	[redacted]		[redacted]
Flow	[redacted]	2.377	[redacted]
	[redacted]		[redacted]
Mid Core (MTC-20)	[redacted]	726.4	[redacted]
Mid Core (MTC-22)	[redacted]	725.3	[redacted]
Mid Core (MTC-24)	[redacted]	719.5	[redacted]
Mid Core (MTC-25)	[redacted]	708.9	[redacted]
Mid Core (MTC-26)	[redacted]	672.5	[redacted]
	[redacted]		[redacted]
Core Top (TTC-8)	[redacted]	786.0	[redacted]
Core Top (TTC-15)	[redacted]	805.1	[redacted]
Core Top (TTC-27)	[redacted]	779.4	[redacted]
Core Top (TTC-28)	[redacted]	809.2	[redacted]
Core Top (TTC-29)	[redacted]	815.4	[redacted]
Core Top (TTC-30)	[redacted]	813.9	[redacted]
Core Top (TTC-31)	[redacted]	812.1	[redacted]
Core Top (TTC-32)	[redacted]	807.0	[redacted]
Core Top (TTC-33)	[redacted]	795.3	[redacted]
Core Top (TTC-34)	[redacted]	763.1	[redacted]
Core Top (TTC-35)	[redacted]	717.7	[redacted]
Core Top (TTC-47)	[redacted]	809.9	[redacted]
Core Top (TTC-53)	[redacted]	802.5	[redacted]
	[redacted]		[redacted]
Above Core (14TC-37)	[redacted]	815.6	[redacted]
Above Core (14TC-39)	[redacted]	822.9	[redacted]
Above Core (14TC-41)	[redacted]	803.3	[redacted]
Above Core (14TC-43)	[redacted]	742.9	[redacted]



Three measuring sections in XX09

MTC h=172 mm

TTC h= 322 mm

14TC h=480 mm

Active region h= 343 mm

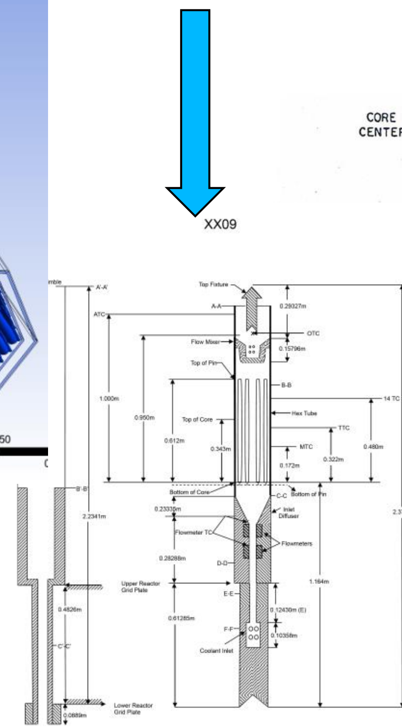
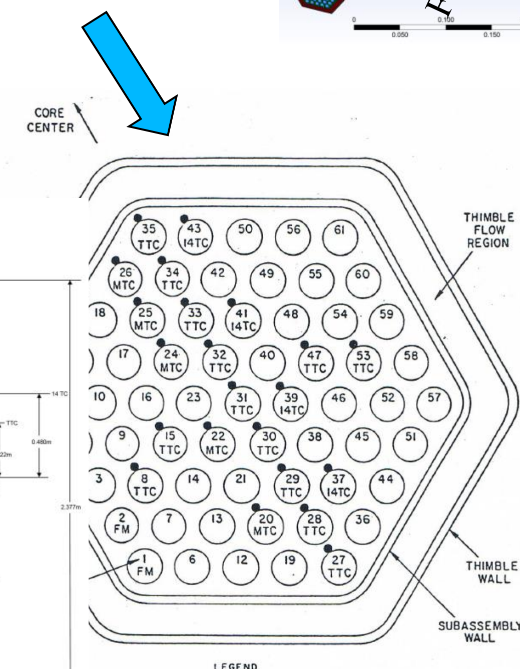


Figure 4.1.7.1. XX09 Instrumented subassembly axial section



SUMMARY

- Nodalization of EBR-II by RELAP5-3D© is available and demonstrate satisfactory behavior in transient: configuration *SHRT-17*
- SHRT-17 blind simulation completed and results have been submitted for the participation in the IAEA CRP on EBR-II
- Comparison with experimental data and analysis of blind simulation carried out
- Post test analysis of SHRT-17 restarted after the delivering of additional experimental data. Those data are relevant and improve the understanding of processes occurring during the transient
- Some CDF and neutronic activities are in progress (i.e. CFX and ERANOS)
- Implementation of SHRT-45 core and system configuration, to achieve steady state conditions and to simulate the transient (unprotected loss of flow) → un-availability of EM component shall be addresed
- The activity on SHRT-17 has been proposed for the publication in the special issue dedicated to RELAP5-3D©. Blind and posttest results will be discussed
- 3rd CRP TM meeting will be hosted by ENEA, 23-27 March 2015